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Potential distribution of *Solidago canadensis* in China

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Abstract The potential distribution of the invasive perennial *Solidago canadensis* in China was assessed by using the homoclime approach. This alien weed spreads rapidly in China, invading abandoned fields and disturbed habitats. It is currently abundant in four provinces of southeastern China, with scattered populations in other provinces to the West and North. We used a climatic profile from the native American range and matched it with data from climatic stations throughout China. To map the potential distribution in China, data were extrapolated to form a grid of 0.1 degree latitude by 0.1 degree longitude. Grid points that fall within the climatic profile are assumed to circumscribe the potential distribution. The potential range in China is remarkably larger than the current range, with parts of northeastern China appearing suitable for *S. canadensis* growth. The latitudes of the potential range span from 25° to 50°. The results show the considerable potential for future spread of *S. canadensis* in China, implying that control measures should be taken to contain this invasive species.

Key words China, homoclime approach, invasive alien plant, potential distribution, prediction, *Solidago canadensis*.

Predicting the potential ranges of invasive alien plants has important ramifications for the management of these species (Lodge et al., 2006). Whereas the species might be difficult to control in areas in which it has already achieved a high abundance, areas not yet colonized but suitable for growth may be subjected to monitoring and control measures may be applied to plants found in such areas. Managing invasive plants at an early stage of establishment is the most cost-effective way (Zamora et al., 1989; Lodge et al., 2006). Estimating potential ranges of terrestrial alien plants can be relatively easily conducted as abundant precipitation and temperature data are available from meteorological stations worldwide, and effective methods have also been developed to calculate indices of biotic responses to climatic variables. In fact, many predictions have been conducted for agricultural weeds (Panetta & Mitchell, 1991a, b) and invasive plants of natural areas (Beerling, 1993; Patterson, 1996; Rejmánek, 2000), which are not only an important part of risk assessments of alien plants (Pheloung & Williams, 1999) but also useful to the understanding of the roles of climate and other abiotic factors in limiting distributions of organisms (Lodge et al., 2006).

Solidago canadensis L. (Asteraceae) is a long-lived rhizomatous perennial of North American origin that belongs to the most widespread invasive alien plants, being naturalized in Europe, New Zealand, Australia, and parts of Asia (Dong et al., 2006b). The species has been introduced to Shanghai in 1935 as an ornamental plant, and it then escaped into the wild (Li et al., 2001). Since then, it has reached a high abundance in four provinces of southeastern China and spreads rapidly to the West and North (Guo, 1995; Li & Xie, 2002; Jin et al., 2004;

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Dong et al., 2006b).

Here, we present an estimation of the potential distribution of *Solidago canadensis* in China, based on homoclime analysis. We make conclusions with regard to future spread and proper management strategies to mitigate effects of this alien plant.

1 Methods

We used the homoclime approach (Panetta & Mitchell, 1991a, b) to predict future spread and the potential range of *Solidago canadensis* in China. Based on eight climatic parameters, we established a climatic profile for *S. canadensis* in China from 37 weather stations located in four provinces, in which *S. canadensis* is widespread and shows high abundance: Shanghai, Jiangsu, Zhejiang and Anhui (Fig. 1). We used this profile (Table 1) to map the minimum distribution range in China, by hypothesizing that the species could grow well under the same climatic conditions as in the four provinces where it is already invasive. The maximum distribution range in China was obtained by implementation of the climatic profile of *S. canadensis* from the native American range (Table 1, Fig. 1). The climate profile of North America for this species was extracted from Weber (2001). In this approach, we hypothesized that this species would reach its maximum distribution range, if it maintained its native growth potential and grew with no other restrictive conditions. The maximum distribution range was also considered as circumscribing the potential distribution.

Climatic data for China were obtained from the China Meteorological Administration (CMA, 1984). Data were available for 958 weather stations throughout China, and consisted of long-term means (1951–1980). Data of the stations were extrapolated to grid points at distances of 0.1 degree latitude and longitude, respectively. Temperature data for the

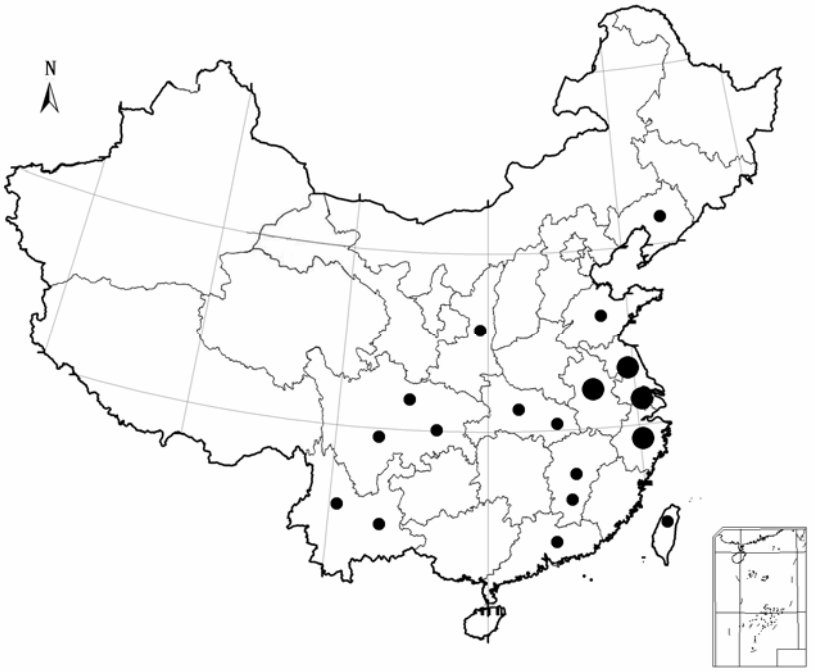

Fig. 1. Current range of *Solidago canadensis* in China. Large dots indicate the provinces in which the species is widespread and has high abundances (up to down: Jiangsu, Anhui, Shanghai, and Zhejiang). Small dots indicate the provinces in which the species is reported, including Liaoning, Shandong, Shaanxi, Sichuan, Yunnan, Hubei, Jiangxi, Guangdong and Taiwan.

Table 1 North American climate profile (NP) and Chinese climate profile (CP) for *Solidago canadensis**

	Climate variables							
	MinT	AnnT	MaxT	DegD	AnnP	MaxP	DryM	WetM
NP								
Min.	−30.7	−2.5	15.8	807	153	93.2	0.5	22.2
Max.	13.0	23.1	33.8	6438	1955	735.8	96.9	324.8
CP								
Min.	−1.2	13.1	26.3	3600	68	150.3	14.4	84.1
Max.	7.6	18.1	29.4	5900	2038	335.7	94.9	335.7

*Only stations with a maximum elevation of 1000 m were considered. Data for NP are from Weber (2001). MinT, minimum monthly mean temperature; AnnT, annual average temperature; MaxT, maximum monthly mean temperature; DegD, degree days above 6 ℃; AnnP, annual average precipitation (mm); MaxP, maximum monthly precipitation (mm); DryM, average precipitation of driest month (mm); WetM, average precipitation of wettest month (mm).

gridpoints were computed by adjusting the location's elevation to sea level and interpolating, followed by extrapolation to the mean elevation of the grid, assuming a temperature lapse rate of 0.6 ℃/100 m. Precipitation data were extrapolated without correcting for elevation (Weng & Zhou, 2006). Grid points falling within the climate profile were mapped.

2 Results and conclusions

The current range of *Solidago canadensis* in China is confined to four provinces in which the species has reached a high abundance, and additional provinces in which the plant is less abundant (Fig. 1). A large area of China can potentially be colonized, indicating that this weed has not yet reached its distribution limit (Fig. 2). These findings are identical to the spread of alien *Solidago* species in Europe (Weber, 2001). In China, suitable areas not yet colonized are situated mainly in the Northeast, with scattered areas in the South. The potential range covers more than twenty degrees of latitude and longitude, respectively.

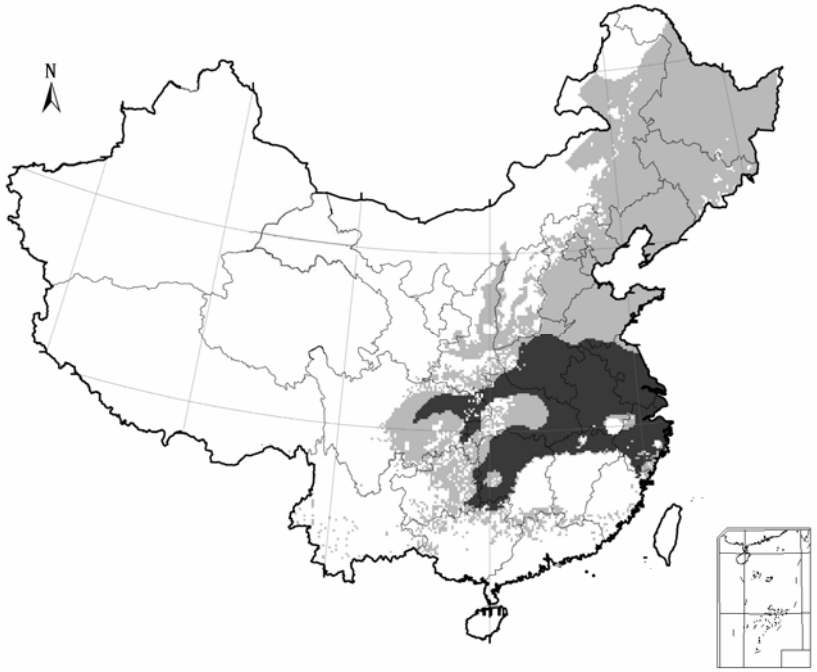

Fig. 2. The minimum (dark shading) and maximum (light shading) potential range of *Solidago canadensis* in China.

The homoclime approach used in this study does not consider other constraints than climatic conditions that limit the species' distribution, such as local soil properties and topography. Considering these local conditions would lead to a more accurate prediction but would require complex models and a much denser set of climatic data. It could be that the minimum and maximum distribution range might be somewhat overestimated, and field investigations could help to make a more accurate prediction. Another assumption of homoclime analysis is the genetic homogeneity, e.g., the species shows no ecotypic variation within the native range and all plants grow equally well at all sites (Howden, 1985). This is unlikely to be the case for *S. canadensis*, as it is a highly variable species both within its native and introduced European (Weber, 2001; Werner et al., 1980) and Chinese (Ma, 2003; Dong et al., 2006a) ranges. The great evolutionary potential of the species may aid its expansion beyond its current range in China. Also, introduced plants can undergo evolution and achieve a greater competitive ability as a result of enemy release (Blossey & Nötzold 1995; Keane & Crawley, 2002), enabling the species to grow better in the introduced range.

Solidago canadensis has been listed as one of the harmful plant invaders in China (Li et al., 2001). It became a serious problem in eastern China, especially in the provinces Shanghai, Zhejiang, Jiangsu and Anhui (Dong, 2006b; Li & Xie, 2002). Our results show that the species is likely to spread further in future. The minimum distribution range as shown in this study should be considered as a high priority area for taking action against this weed. The species has already caused economic and ecological losses, so we suggest that the resources may be allocated to eradication of this species at its early stage of spread within the minimum distribution range. This requires the development of efficient control techniques.

A vast area in northeastern China has suitable climatic conditions for this species, where large plains are typical landscape features and which is an important agricultural area for China. Therefore, if *Solidago canadensis* can colonize these areas with no further restrictions, the impact of this species might become much greater. In the South, areas potentially suitable for *S. canadensis* are relatively scattered, because the landscape is mountainous, which may confine this plant only to roadsides, abandoned fields, and agricultural lands of lower elevations. Monitoring the spread and eradicating small populations would be the appropriate measure in this area. We assume that *S. canadensis* is currently unlikely to become a threat in areas outside of the maximum distribution range; and under this assumption these areas may be considered as a low priority area. Thus, based on the potential distribution, available resources for control should be allocated according to different priority levels.

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加拿大一枝黄花在中国的潜在入侵区预测

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摘要 加拿大一枝黄花*Solidago canadensis*是原产于北美的菊科Asteraceae多年生草本植物, 上世纪30年代引入我国, 现广泛分布于我国东部地区的部分省市, 并已成为该区域的农业和环境杂草。为了预测加拿大一枝黄花在我国的潜在分布区, 本研究采用相同气候方法对其进行了估测。我们用加拿大一枝黄花的原产地——美国的气候参数作为参照, 将其与我国各地气象站的气候数据进行匹配。结果表明, 加拿大一枝黄花在我国的潜在分布区的纬度跨度为25°–50°, 所以其潜在的入侵区将远大于目前的实际分布区, 甚至东北的部分地区也将适宜于该物种的生长。据此, 我们建议相关管理部门应加强该物种的监测工作, 以防其进一步向目前入侵区以外的周边地区蔓延。

关键词 中国; 相同气候方法; 外来入侵种; 潜在分布区; 预测; 加拿大一枝黄花